



(12) **United States Patent**  
**Lane et al.**

(10) **Patent No.:** **US 9,316,162 B2**  
(45) **Date of Patent:** **Apr. 19, 2016**

(54) **METHOD OF CONTROLLING A FUEL SUPPLY SYSTEM OF AN ENGINE OF A MOTOR VEHICLE**

USPC ..... 701/112, 113; 123/445, 447, 456  
See application file for complete search history.

(71) Applicant: **Ford Global Technologies, LLC,**  
Dearborn, MI (US)

(56) **References Cited**

U.S. PATENT DOCUMENTS

(72) Inventors: **Stuart Lane**, Stratford (GB); **Donatus Andreas Josephine Kees**, Billerica (GB)

4,683,844 A 8/1987 Arai et al.  
7,574,994 B2 8/2009 Scheurer et al.  
7,717,077 B2 5/2010 Prior  
8,091,518 B2 1/2012 Shikida et al.

(Continued)

(73) Assignee: **Ford Global Technologies, LLC,**  
Dearborn, MI (US)

FOREIGN PATENT DOCUMENTS

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 238 days.

EP 0886058 B1 11/2004  
JP H04246253 A 9/1992

(Continued)

(21) Appl. No.: **14/103,689**

OTHER PUBLICATIONS

(22) Filed: **Dec. 11, 2013**

“Fuel Supply System to the Low-Pressure Stage,” excerpt from Diesel-Engine Management, pp. 82-89, 3rd Ed., Bosch Handbooks (REP) Series, #3, Published Feb. 27, 2004, 7 pages.

(65) **Prior Publication Data**

US 2014/0163847 A1 Jun. 12, 2014

(30) **Foreign Application Priority Data**

Dec. 12, 2012 (GB) ..... 1222303.8

Primary Examiner — John Kwon

(74) Attorney, Agent, or Firm — Julia Voutyras; Alleman Hall McCoy Russell & Tuttle LLP

(51) **Int. Cl.**

**G06F 19/00** (2011.01)  
**F02D 33/00** (2006.01)  
**F02D 41/04** (2006.01)  
**F02D 41/38** (2006.01)  
**F02D 41/40** (2006.01)  
**F02M 37/00** (2006.01)

(52) **U.S. Cl.**

CPC ..... **F02D 33/006** (2013.01); **F02D 41/042** (2013.01); **F02D 41/3845** (2013.01); **F02D 41/406** (2013.01); **F02M 37/0041** (2013.01); **Y02T 10/44** (2013.01)

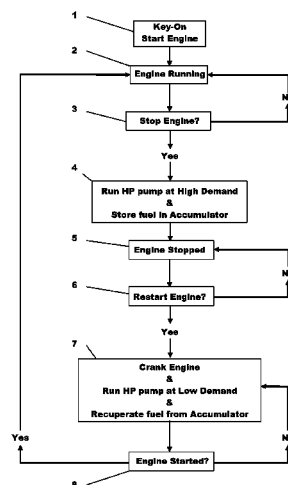
(58) **Field of Classification Search**

CPC ..... F02D 41/042; F02D 41/06; F02D 41/062

(57) **ABSTRACT**

A method of controlling a fuel supply system of an engine 10 of a motor vehicle 50 is disclosed in which an engine driven variable output high pressure fuel pump is operated at a high demand level to charge a high pressure fuel accumulator with fuel during a shutdown of the engine and, during a subsequent start-up of the engine, use fuel from the accumulator while operating the high pressure fuel pump at a low demand level. This reduces the fuel consumption of the engine by using kinetic energy from the slowing engine to drive the high pressure fuel pump and increases the deceleration of the engine.

**20 Claims, 11 Drawing Sheets**



# US 9,316,162 B2

Page 2

(56)

## References Cited

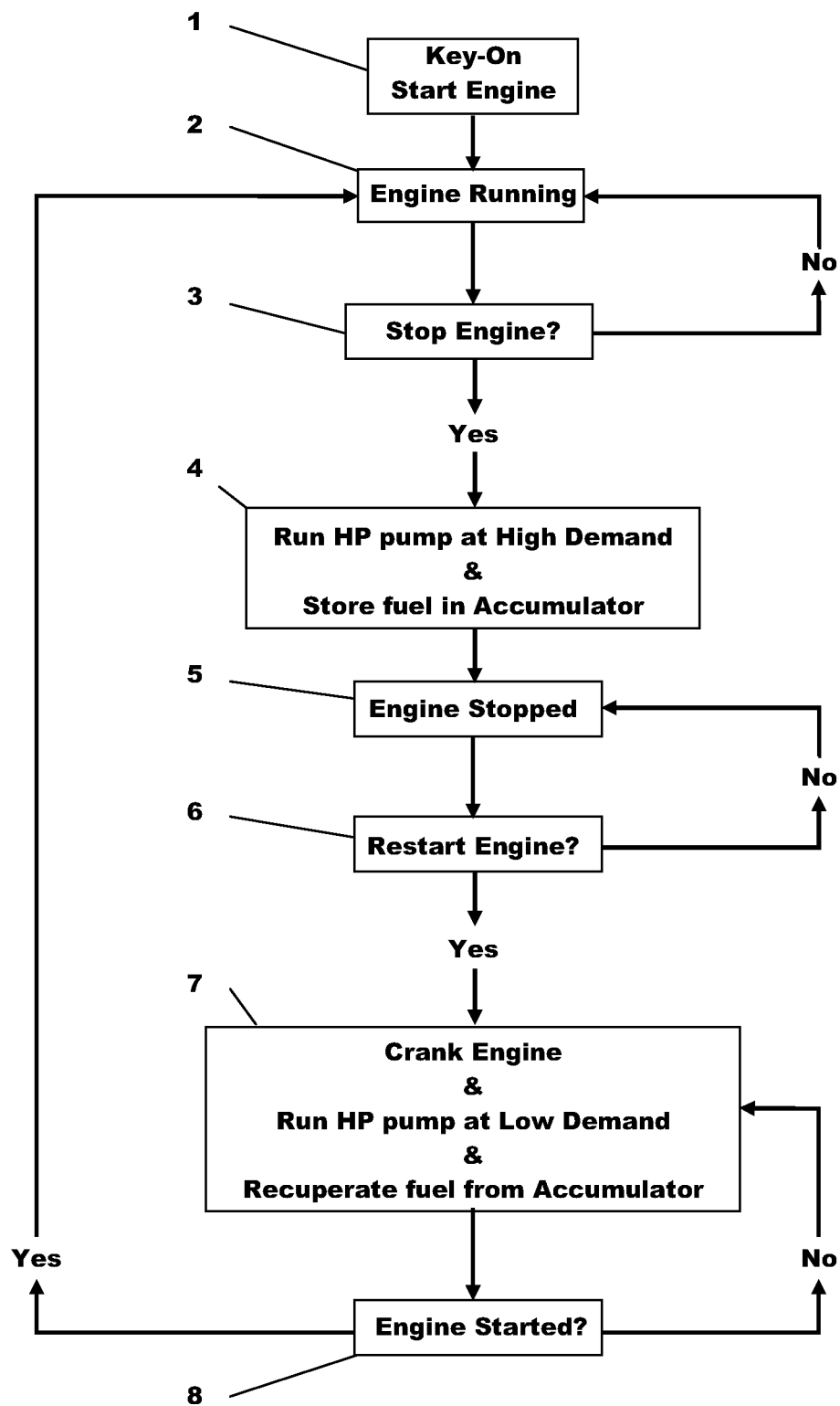
## FOREIGN PATENT DOCUMENTS

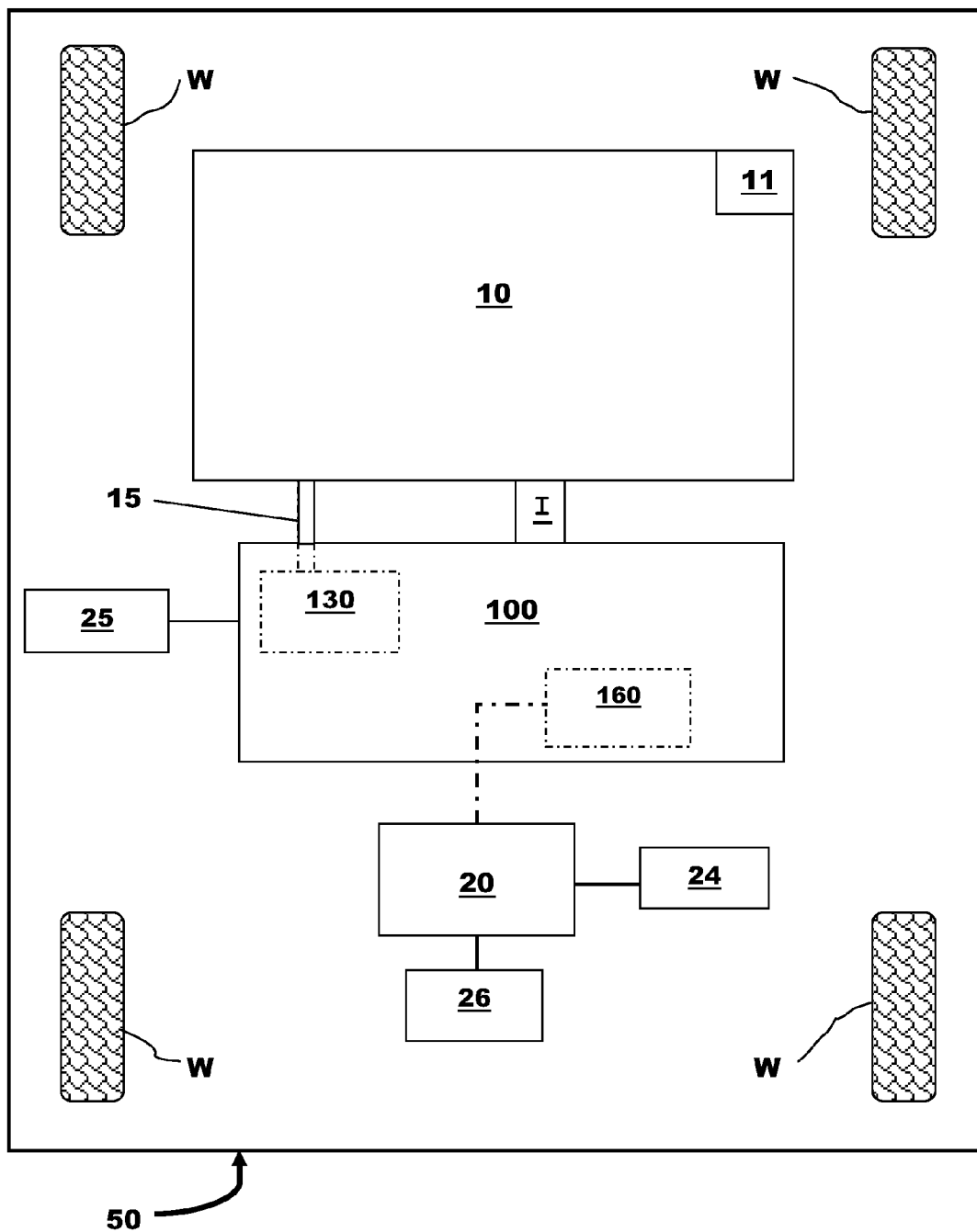
### U.S. PATENT DOCUMENTS

2002/0184884 A1\* 12/2002 McCarty ..... F02C 7/22  
60/773  
2009/0120397 A1 5/2009 Prior  
2010/0050433 A1 3/2010 Harada et al.  
2011/0214643 A1\* 9/2011 Blizard ..... F02M 53/02  
123/468  
2013/0110383 A1\* 5/2013 McDonald ..... F02D 41/042  
701/113

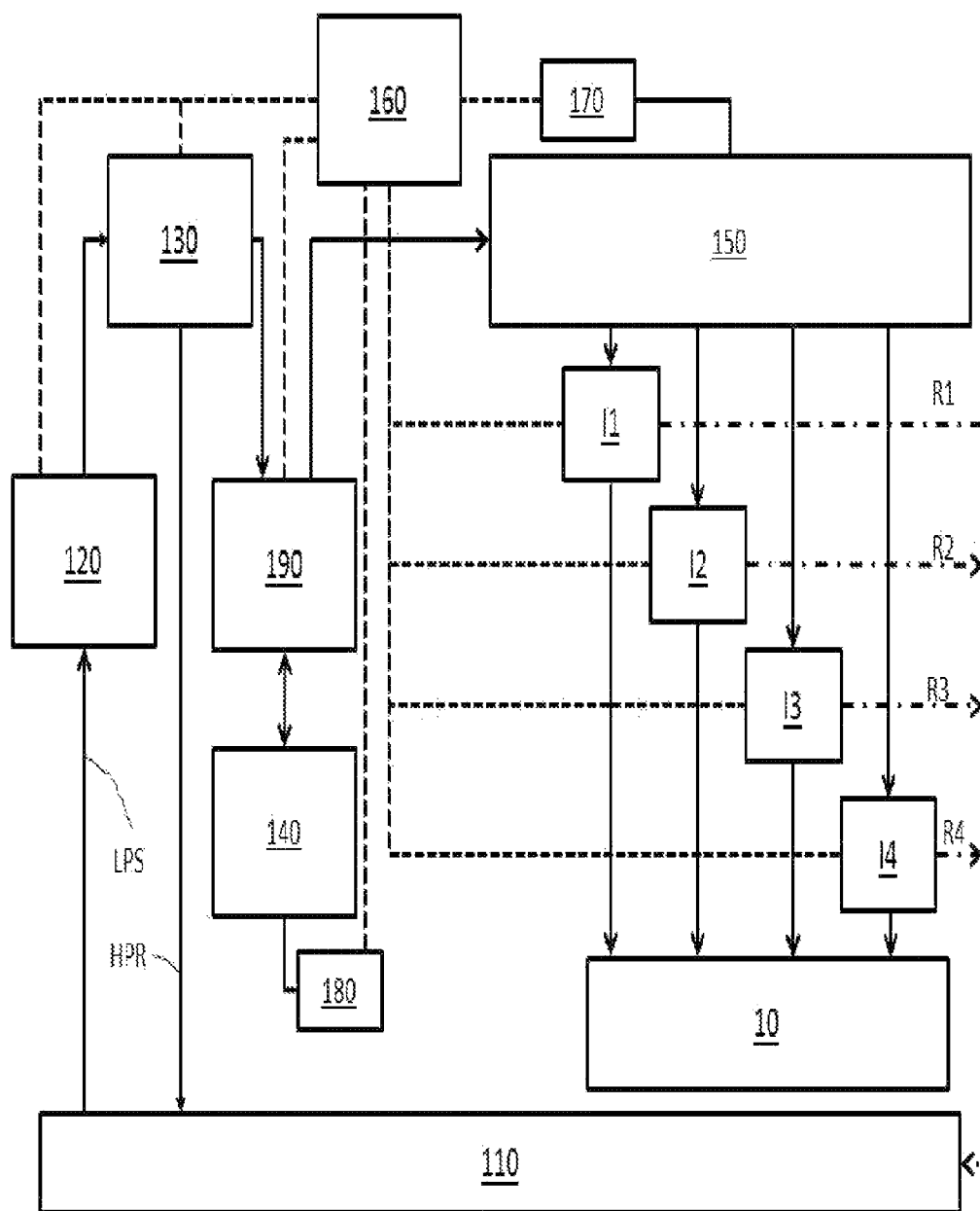
JP H10159683 A 6/1998  
JP 2000054926 A 2/2000  
JP 2003065104 A 3/2003  
JP 2004036459 A 2/2004  
JP 2004301047 A 10/2004  
JP 2006348908 A 12/2006  
JP 2011132872 A 7/2011

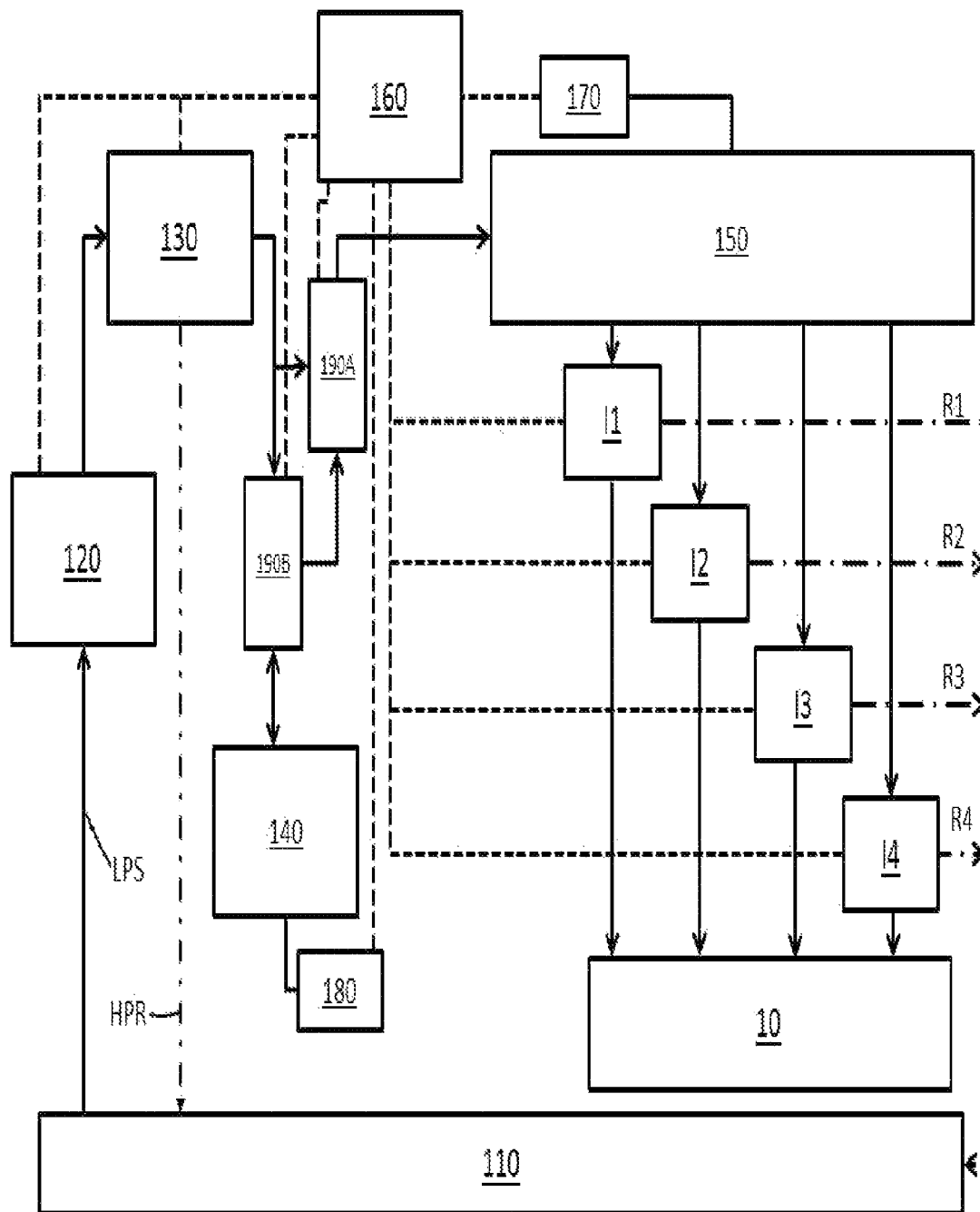
\* cited by examiner

**Fig.1**

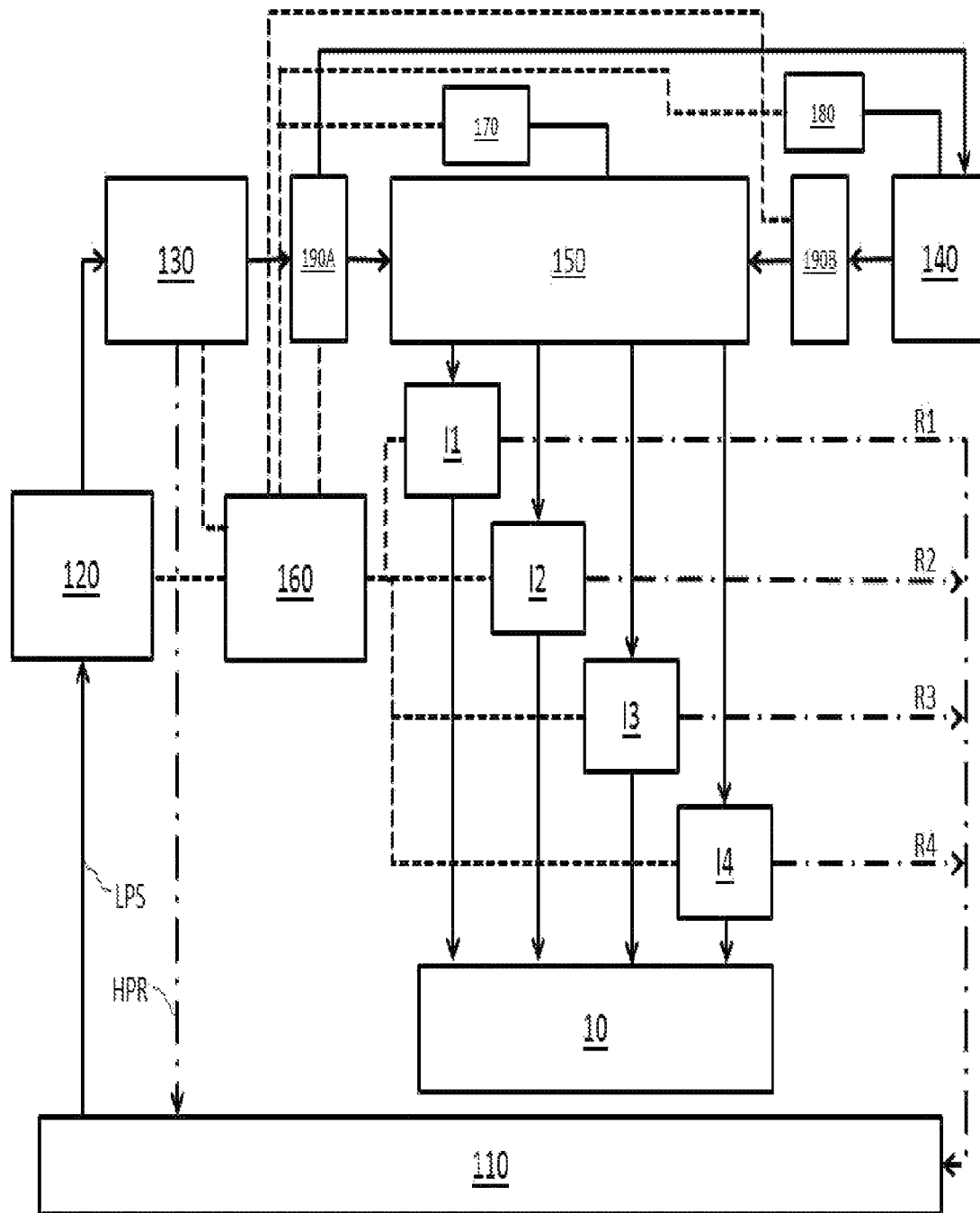


**Fig.2**

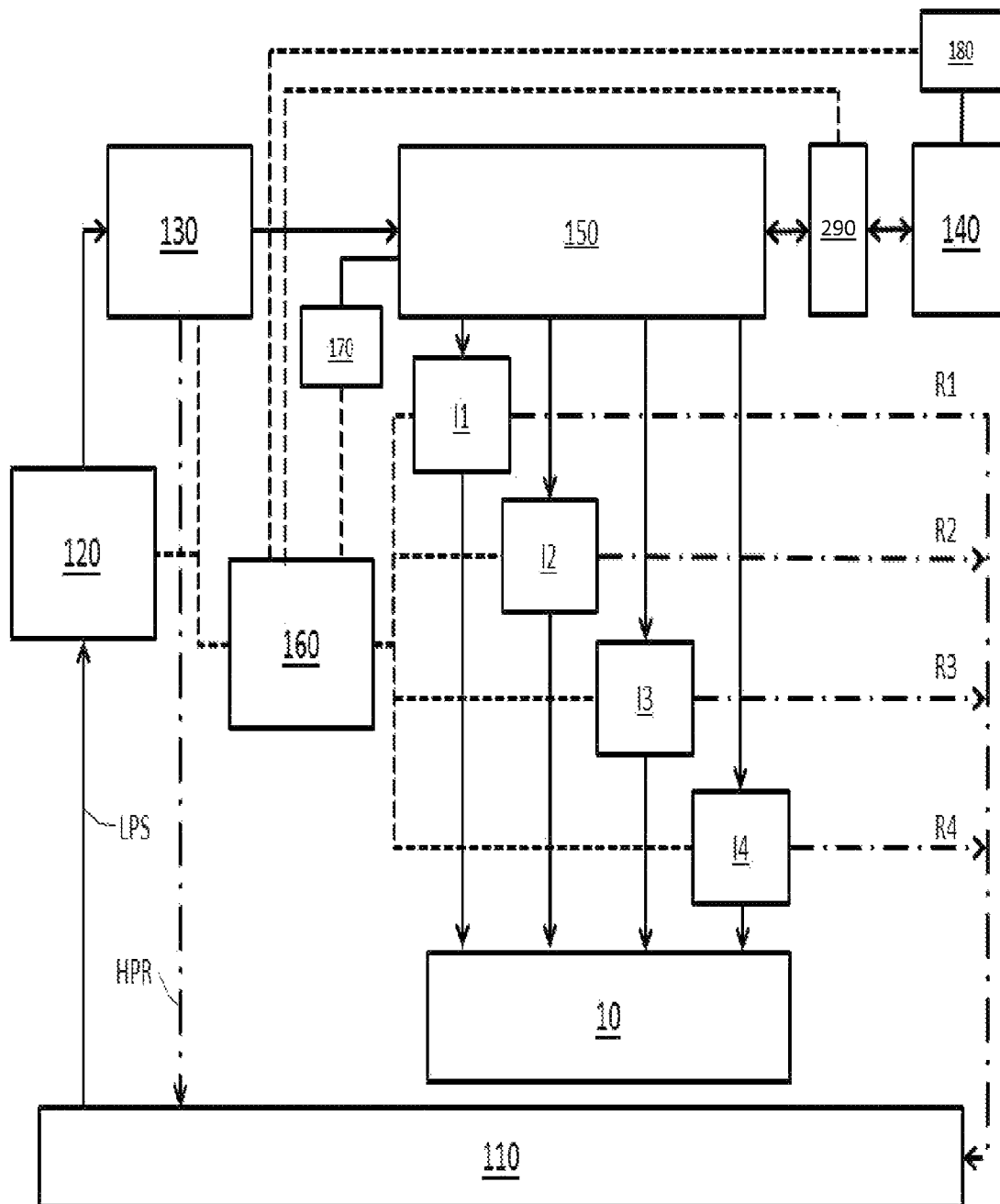
**Fig.3**



**Fig.4**

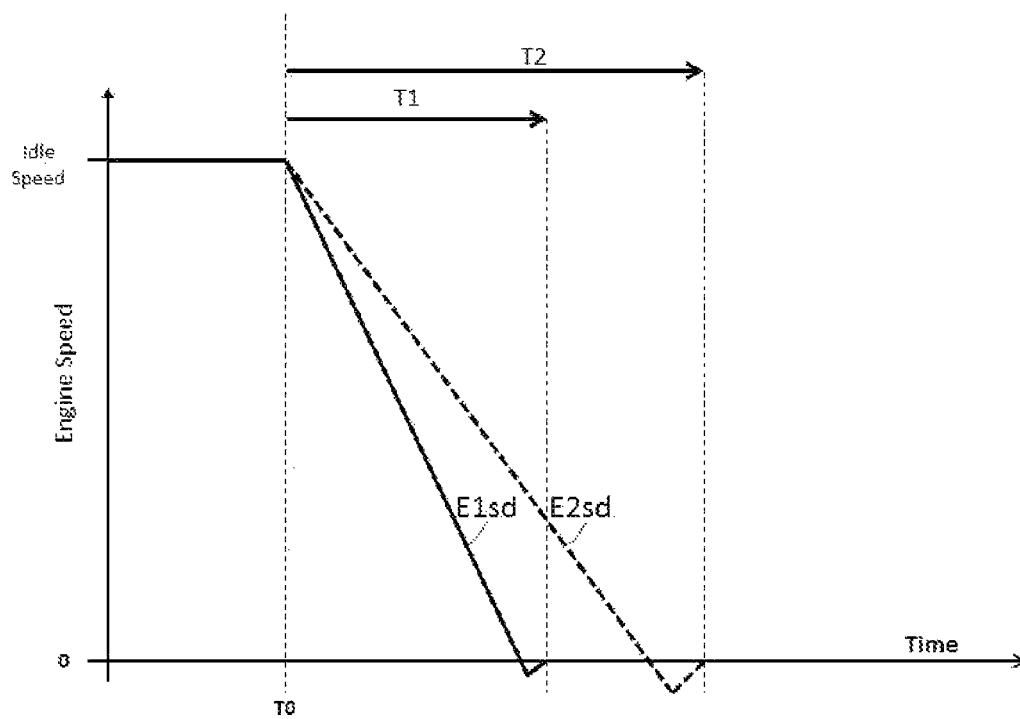


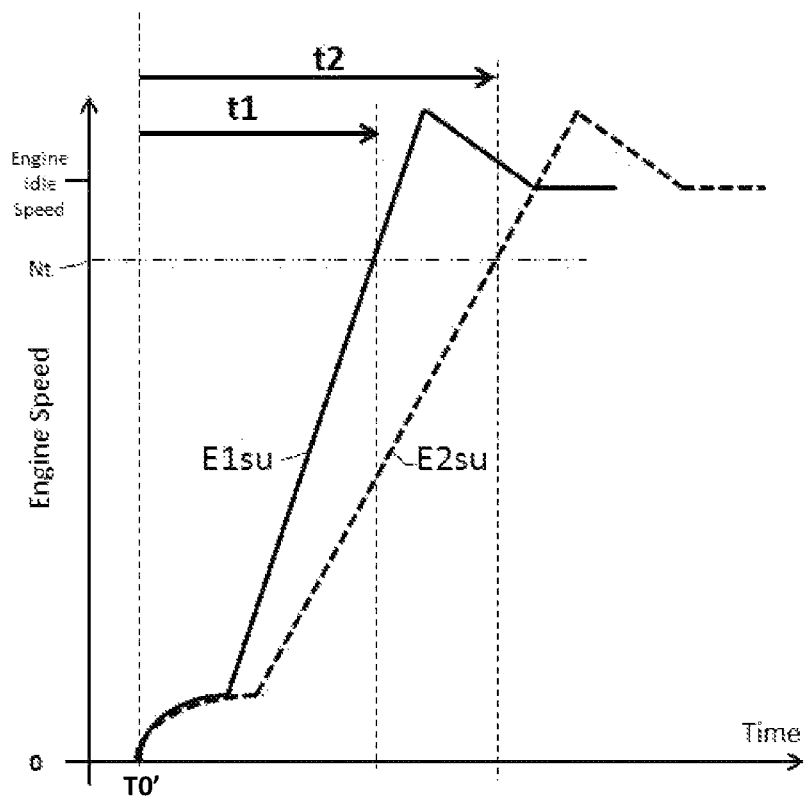
**Fig.5**



**Fig.6**



**Fig.7**

**Fig.8**

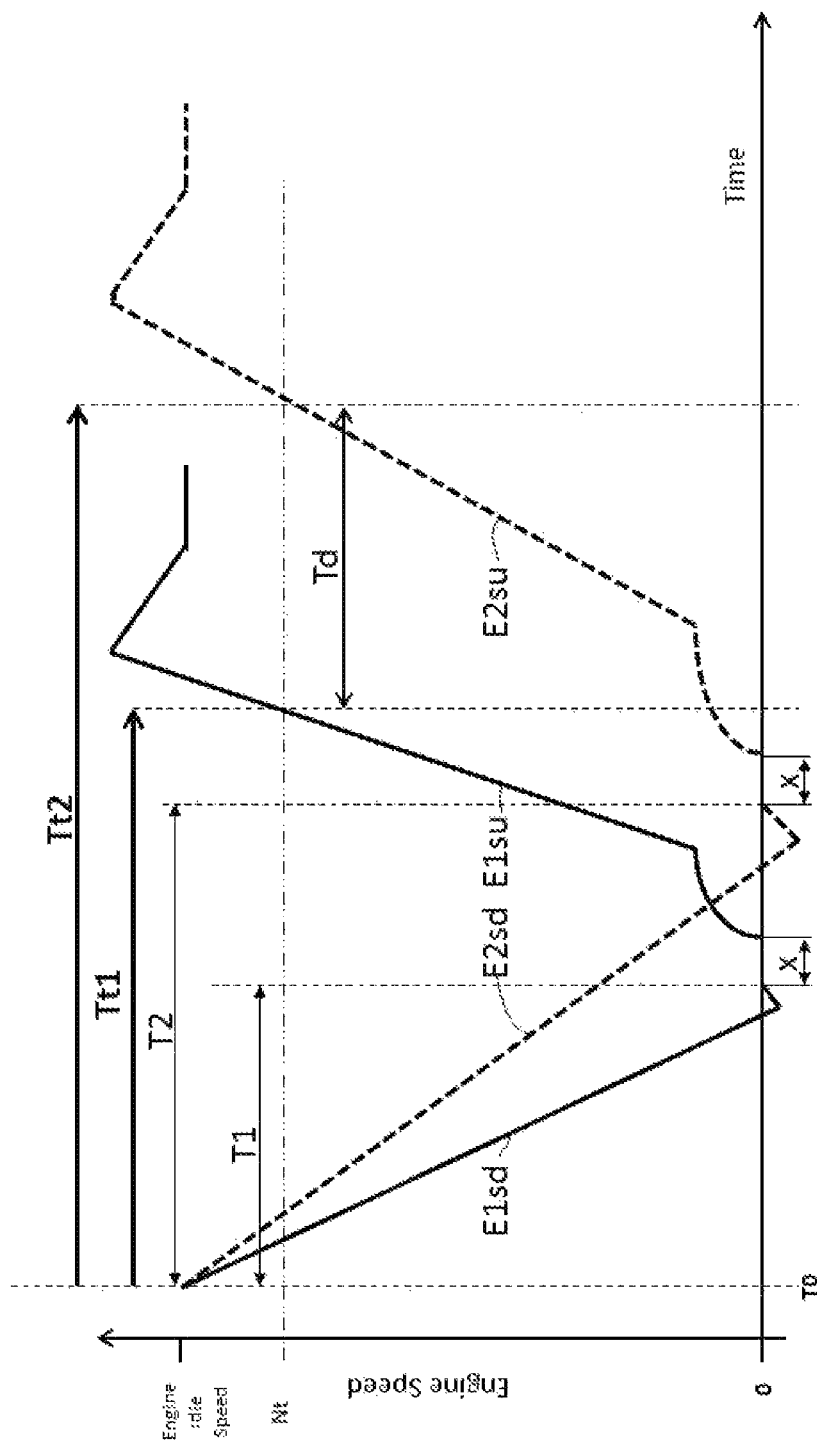
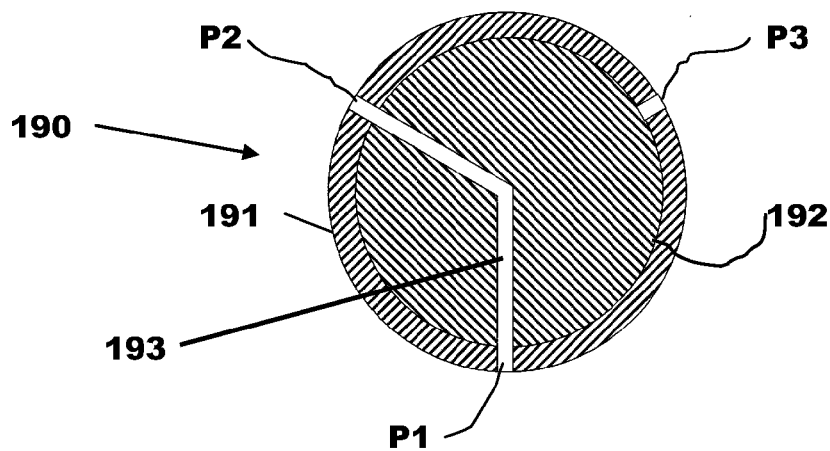
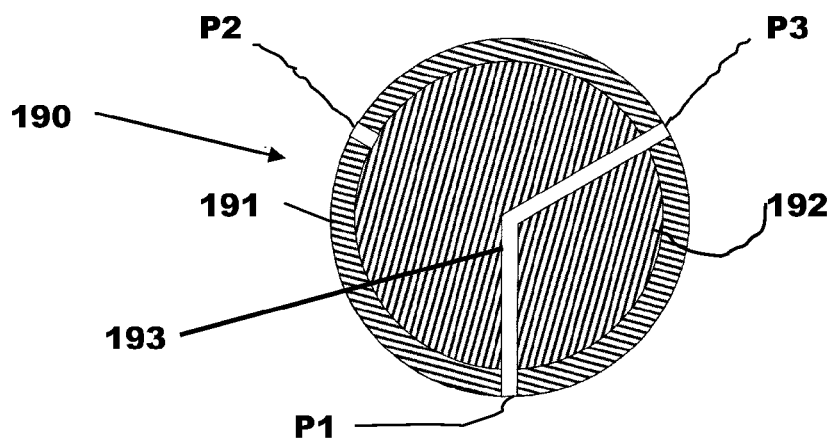


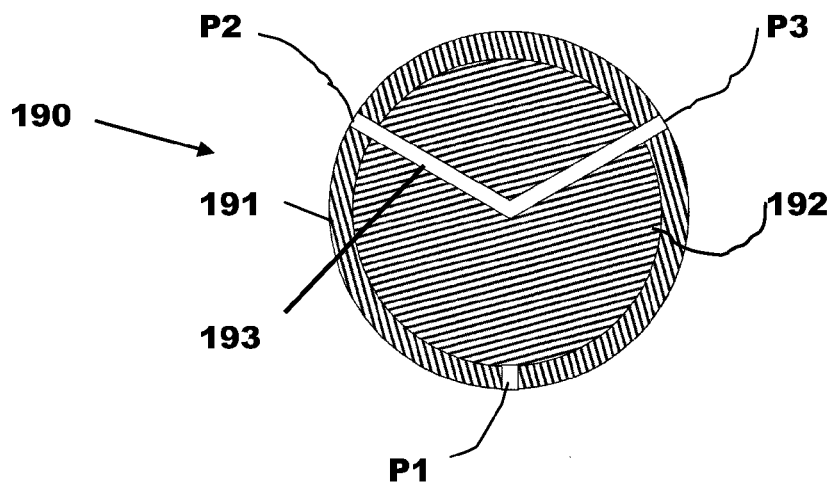
Fig.9



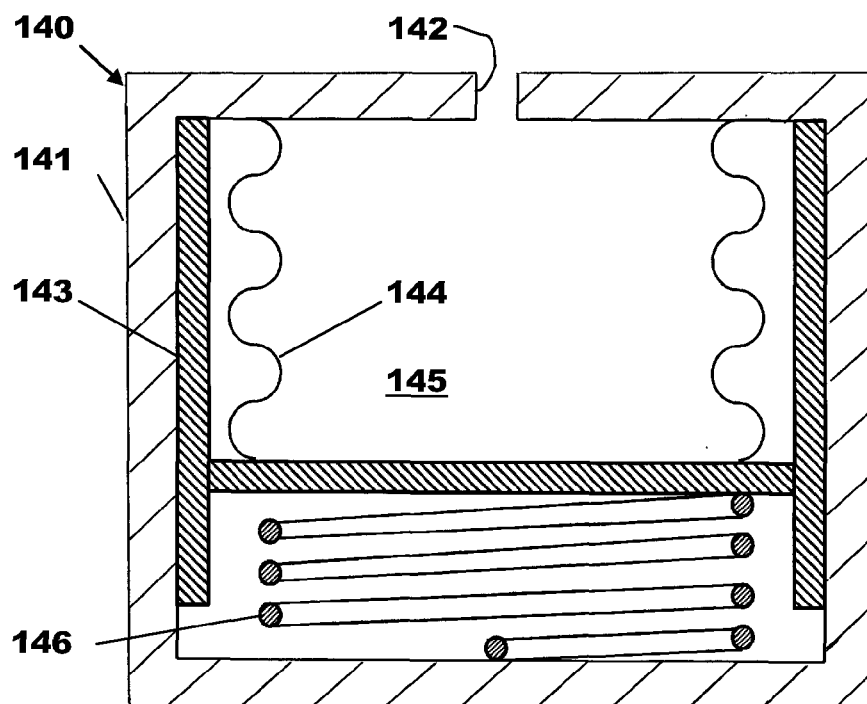
**Fig.10a**



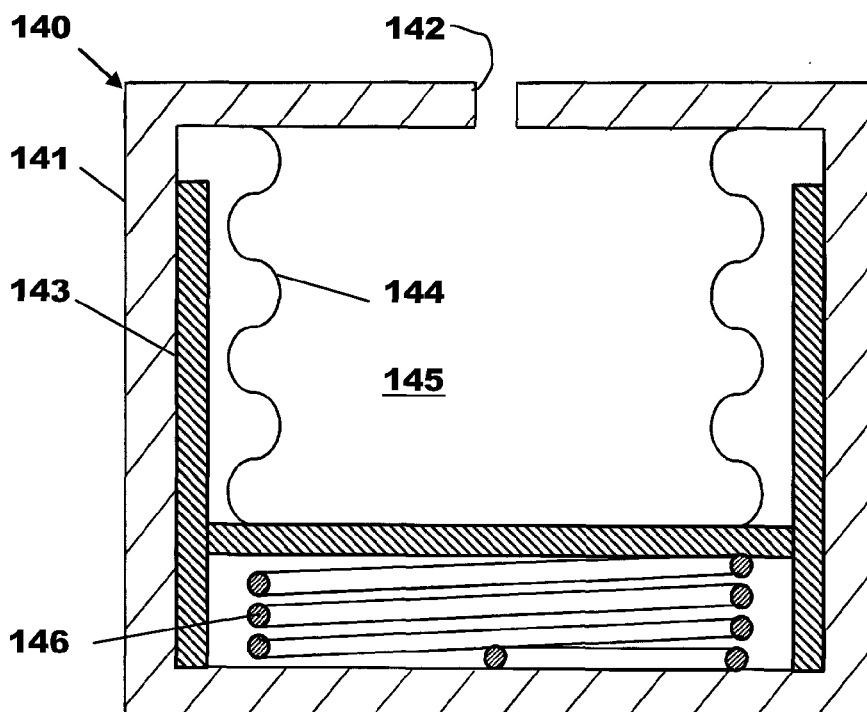
**Fig.10b**



**Fig.10c**



**Fig.11a**



**Fig.11b**

1

# METHOD OF CONTROLLING A FUEL SUPPLY SYSTEM OF AN ENGINE OF A MOTOR VEHICLE

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority to Great Britain Patent Application No. 1222303.8, entitled "A Method of Controlling a Fuel Supply System of an Engine of a Motor Vehicle," filed on Dec. 12, 2012, the entire contents of which are hereby incorporated by reference for all purposes.

## FIELD

This invention relates to motor vehicles and in particular to the control of a fuel system of an engine of a motor vehicle during shutdown and start-up of the engine.

## BACKGROUND/SUMMARY

It is known to provide a motor vehicle with an engine stop-start system for automatically stopping and starting the engine whenever it is determined from driver actions that there is an opportunity to do so in order to reduce fuel consumption and reduce emissions from the engine.

However, the inventors herein have recognized potential issues with such engine stop-start systems. As one example, if the time taken to stop and then restart the engine is excessive, the delay may lead to dissatisfaction in a user of the motor vehicle. In addition, such an excessive delay, may also result in actual use problems if the driver wrongly concludes that the system has failed to restart the engine in response to their actions.

In one example, the issues described above may be addressed by a method for . . . controlling a fuel supply system of an engine of a motor vehicle wherein the method comprises, during a shutdown of the engine, operating an engine driven variable output high pressure fuel pump at a high demand level and storing fuel from the high pressure fuel pump in a fuel accumulator and, during a subsequent engine start-up, operating the high pressure fuel pump at a low demand level and supplying fuel from the accumulator to the engine.

In another example, a fuel supply system of an engine of a motor vehicle comprising an engine driven variable output high pressure fuel pump, a fuel accumulator to store fuel at high pressure, a valve means to control the flow of high pressure fuel within the system and an electronic controller to control the operation of the high pressure fuel pump and the valve means, wherein the controller is operable during a shutdown of the engine, to operate the high pressure fuel pump at a high demand level and control the valve means to store fuel from the high pressure fuel pump in the fuel accumulator and is operable, during a subsequent engine start-up, to operate the high pressure fuel pump at a low demand level and operate the valve means so that fuel from the fuel accumulator is supplied to the engine.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

2

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a method of controlling a fuel system of an engine of a motor vehicle in accordance with a first aspect of the invention.

FIG. 2 shows a schematic plan view of a motor vehicle according to a third aspect of the invention having a fuel supply system according to a second aspect of the invention

FIG. 3 shows a schematic diagram of a first embodiment of the fuel supply system shown in FIG. 2

FIG. 4 shows a schematic diagram of a second embodiment of the fuel supply system shown in FIG. 2

FIG. 5 shows a schematic diagram of a third embodiment of the fuel supply system shown in FIG. 2

FIG. 6 shows a schematic diagram of a fourth embodiment of the fuel supply system shown in FIG. 2.

FIG. 7 shows an engine speed versus time chart comparing the shutdown of a prior art engine and an engine having a fuel supply system constructed in accordance with said second aspect of the invention and operated in accordance with a method in accordance with said first aspect of the invention

FIG. 8 shows an engine speed versus time chart comparing the start-up of a prior art engine and an engine having a fuel supply system constructed in accordance with said second aspect of the invention and operated in accordance with a method in accordance with said first aspect of the invention

FIG. 9 shows an engine speed versus time chart comparing the shutdown and start-up of a prior art engine and an engine having a fuel supply system constructed in accordance with said second aspect of the invention and operated in accordance with a method in accordance with said first aspect of the invention.

FIG. 10A-C shows a diagrammatic representations of a high pressure fuel flow diverter valve showing the valve in three different flow path states

FIG. 11A-B shows a diagrammatic representations of a high pressure fuel accumulator suitable for use in a fuel supply system constructed in accordance with said second aspect of this invention

## DETAILED DESCRIPTION

With reference to FIG. 1 there is shown a high level flow chart of a method of controlling a fuel supply system of an engine of a motor vehicle according to the invention.

The method starts at box 1 which are manual key-on and engine start events. The method then advances to box 2 where the engine is running and then on to box 3 where it is checked whether the engine is to be stopped. This can be a manual stop by a driver of the motor vehicle or an automated stop initiated by a stop-start system in the case of a stop-start enabled motor vehicle.

If the engine is not to be stopped the method returns to box 2 and then cycles between boxes 2 and 3 until the engine is to be stopped. When it is determined in box 3 that the engine is to be stopped the method advances to box 4 where a variable output high pressure fuel pump for the engine is operated at a high demand level and fuel pumped by the high pressure pump is stored in a high pressure fuel accumulator until, as indicated in box 5, the engine has stopped. Preferably, the high pressure fuel pump is operated at its maximum demand level because this will impose the greatest load on the engine. The pressure of the fuel stored in the accumulator is at a pressure suitable for injection into the engine as described with respect to a start-up of the engine hereinafter.

There are two primary advantages associated with the processes described in box 4. Firstly, during the subsequent

3

engine cranking and re-start no electricity from the battery and hence no fuel has to be used by the engine to charge the accumulator with high pressure fuel because kinetic energy from the slowing engine is recovered to drive the high pressure pump thereby improving the overall fuel consumption of the engine. Secondly, because operating the high pressure fuel pump at a high demand level requires a considerable driving force to be provided from the engine, the high pressure fuel pump acts as a brake increasing the rate at which the engine slows down. This braking effect will reduce the time taken for the engine to stop after the engine stop is initiated and will also reduce any tendency for the engine to run in reverse (overshoot zero) which is undesirable. In the case of a stop-start enabled motor vehicle the time taken for the engine to stop is important because it significantly affects the minimum cycle time possible for a stop-start event. Therefore, if the engine needs to be restarted as soon as it has stopped, a shorter shutdown period will allow the engine to be started sooner than would otherwise be the case.

After box 5 the method advances to box 6 with the engine stopped and, in box 6, it is checked whether the engine is to be restarted. If the engine is not to be restarted, the method cycles back through box 5 to box 6 with the engine stopped. However, if in box 6 it is confirmed that the engine is to be started, the method advances from box 6 to box 7. The restart can be a manual one by the driver of the motor vehicle or an automated start initiated by a stop-start system in the case of a stop-start enabled motor vehicle.

In either case, in box 7 the engine is cranked by a starter motor or any other suitable cranking device such as, for example and without limitation, an integrated starter generator (ISG), the high pressure fuel pump is operated at a low demand level and fuel is recuperated from the accumulator to fuel the engine by means of one or more fuel injectors. Because the fuel stored in the accumulator is at a pressure suitable for injection into the engine via the fuel injectors, there is no need for fuel to be supplied from the high pressure fuel pump during the engine start-up and so the low demand level set is advantageously the minimum demand level possible for the high pressure fuel pump and is preferably a demand level of zero.

One advantage of the use of a low demand level is that it reduces the load normally imposed by the high pressure fuel pump on the engine and therefore reduces the time taken for the engine to reach a self-sustaining rotational speed for the engine and, perhaps more importantly, the time taken to reach a speed  $N_t$  where useful torque can be produced by the engine. The speed  $N_t$  is an engine speed below which the application of a load to the engine will likely result in stalling of the engine whereas above this speed  $N_t$  useful torque can be produced.

One advantage of the use of fuel from the accumulator during the start-up is that, if an engine driven high pressure fuel pump is used to provide fuel for the engine, the engine cannot be started at the first available opportunity because it takes time for the high pressure fuel pump to build pressure after drive to the fuel pump commences. However, by using fuel stored in the accumulator at a pressure that it is suitable for efficient injection to the engine, then, as soon as the first opportunity for injection occurs, fuel can be injected into the engine thereby further reducing the time taken for the engine to reach the self-sustaining speed.

The method advances from box 7 to box 8 where it is checked whether the engine has started, that is to say reached a self-sustaining rotational speed where the starter motor can be switched off or disengaged. If the self-sustaining engine

4

speed has not been reached, the method cycles back through box 7 to box 8 until the self-sustaining engine speed has been reached.

In the event that the engine has failed to start and the fuel in the accumulator has been exhausted to a level where there is no longer sufficient pressure to provide efficient fuel injection for the engine then, although not shown on FIG. 1, a fault routine is enabled in which fuel is provided from the high pressure fuel pump to the engine. If, after a predetermined period of time, the engine has still not started a warning can be given to the driver of the motor vehicle and starting of the engine can be temporarily inhibited to prevent damage occurring to the starter motor.

Referring back to box 8, if the engine has started then the method returns to box 2 with the engine running.

After the engine has reached the required self-sustaining speed the fuel supply may be switched from the accumulator to the fuel pump or may remain from the accumulator until the pressure in the accumulator falls to a predefined level or a power demand for the engine is above a predefined level.

It will be appreciated that the above method can be ended at any time by a manual key-off event. In the event of a manual key-off event occurring it is preferable if the method steps of box 4 are used because then fuel is stored without incurring a fuel penalty that can be used in a subsequent key-on and start-up event such as that shown as box 1 in FIG. 1. That is to say, box 1 could include the steps shown in box 7 of FIG. 1. This has the advantages of reduced fuel use and improved start-up performance. The reduced driving force required from the high pressure fuel pump during start-up would be particularly advantageous in the case of a cold start-up of a diesel engine where the combination of high friction and cranking loads place a considerable strain on the starter motor and associated electrical system.

The above method is particularly advantageous in the case of a stop-start enabled motor vehicle because it significantly reduces the time taken to stop and then restart the engine and so reduces the risk of driver dissatisfaction or erroneous conclusions regarding the operating state of the stop-start system.

With particular reference to FIG. 2 there is shown a motor vehicle 50 having four road wheels 'W', a diesel engine 10, a fuel supply system 100 for the engine 10 and a stop-start system 20. Although the invention is described with reference to a diesel engine it will be appreciated that it could be applied to other engine types that utilise a high pressure fuel injection system such as, for example and without limitation, a direct injection gasoline engine.

The engine 10 is driveably connected in this case to two of the road wheels by a transmission (not shown) but it will be appreciated that the transmission could in other embodiments driveably connect the engine 10 to all four of the road wheels 'W'. It will also be appreciated that the invention is not limited to use with a four wheeled road vehicle and could be applied to a vehicle having two wheels or more than four wheels.

A starter motor 11 is provided to the start when required the engine 10. It will however be appreciated that any suitable cranking means could be used.

The fuel system 100 receives a number of vehicle information inputs 25 that are used by the fuel supply system 100 to control the fuelling of the engine 10 via one or more fuel injectors 'I'. Such inputs 25 are well known in the art and may include, for example and without limitation, engine speed, driver demand, mass air flow, air temperature, coolant temperature, ambient temperature and ambient atmospheric pressure.

5

The fuel supply system includes an electronic controller **160** and an engine driven variable output high pressure fuel pump **130** that is driven, as is well known in the art, by a mechanical drive **15** from one end of a camshaft (not shown) of the engine **10**. It will however be appreciated by those skilled in the art that other mechanical drive means could be used and that the invention is not limited to the use of a camshaft driven high pressure fuel pump **130**.

Variable output high pressure fuel pumps are known from, for example and without limitation, US Patent Application 20120177505 and PCT patent publication WO2012113488.

The fuel supply system **100** is described in greater detail with reference to four embodiments shown FIGS. **3** to **6** respectively hereinafter.

The motor vehicle is in this case a 'stop-start enabled' motor vehicle **50** because the engine **10** can be stopped and started automatically by the stop-start system **20** based upon driver and vehicle information inputs **24**, **25**. It will be appreciated that the invention could be applied to a motor vehicle that is not 'stop-start enabled' or to a hybrid motor vehicle whether or not the hybrid vehicle is 'stop-start enabled'. However, the invention is particularly advantageous with respect to its use on any 'stop-start enabled' motor vehicle.

The driver inputs **24** are inputs that provide information to the stop-start system **20** regarding operation of vehicle controls such as, for example, the movement or position of an accelerator pedal, a brake pedal or a clutch pedal or the engagement state of the transmission.

The vehicle information inputs **26** are inputs that provide information to the stop-start system **20** regarding operation of the motor vehicle **50** such as, for example and without limitation, the speed of the motor vehicle, engine speed, the temperature of coolant for the engine, the operating state of an air-conditioning unit if fitted, the state of charge of a battery of the motor vehicle.

Such stop-start systems are well known in the art and the functionality and logic applied in such systems is not relevant to the enablement of this invention. It is merely necessary to know that the stop-start system **20** is operable to stop the engine **10** when a particular combination of driver input states and vehicle information input states is present and restart the engine **10** when a further set of driver input states and vehicle information input states is present.

Although the electronic controller **160** of the fuel supply system **100** and the stop-start controller **20** are shown in FIG. **2** as separate units it will be appreciated that they could be embodied as a single electronic controller such as a powertrain controller.

Referring now to FIG. **3** there is shown in greater detail a first embodiment of the fuel supply system shown in FIG. **2**.

The fuel supply system **100** comprises of a fuel reservoir or fuel tank **110** used to store fuel for use by the engine **10**. Fuel is drawn from the fuel tank **110** by a low pressure fuel pump **120** and is supplied to an inlet of the variable output high pressure fuel pump **130** via a low pressure fuel supply line LPS. The high pressure fuel pump **130** is controlled by the electronic controller **160** between a minimum demand level and a maximum demand level. The minimum demand level will preferably result in a fuel flow rate from the high pressure fuel pump **130** of substantially zero and the maximum demand level will result in the maximum possible flow from the high pressure fuel pump **130** for the current engine speed. When operating at the minimum demand level, the high pressure fuel pump **130** requires a minimal driving force to be provided from the engine **10** and, when operating at the maximum demand level, the high pressure fuel pump **130** requires a high driving force to be supplied from the engine **10**. Excess

6

or leaked fuel from the high pressure fuel pump **130** is returned to the fuel tank **110** via a low pressure return line HPR.

A valve means in the form of a single electronically controlled three way diverter valve **190** is connected to an output from the high pressure fuel pump **130** so as to receive a flow of fuel at high pressure therefrom.

The diverter valve **190** is best understood with reference to FIGS. **10a** to **10c** and has three selectable fuel flow paths. By way of example, a rotary diverter valve **190** is shown in FIGS. **10a** to **10c** having a body **191** in which is rotatably mounted a valve member **192** defining a fuel flow passage **193**. The body **191** has first port P1 connected to the high pressure fuel pump **130**, a second port P2 connected to a common fuel rail **150** and a third port P3 connected to a high pressure fuel accumulator **140**.

The diverter valve **190** is interposed between the high pressure fuel pump **130** and the common fuel rail **150**, between the high pressure fuel pump **130** and the accumulator **140** and between the accumulator **140** and the common fuel rail **150**.

In FIG. **10a** the valve member **192** is shown in a position in which the fuel flow passage **193** defines a first flow path connecting the high pressure fuel pump **130** to the common fuel rail **150**.

In FIG. **10b** the valve member **192** is shown in a position in which the fuel flow passage **193** defines a second flow path connecting the high pressure fuel pump **130** to the accumulator **140**.

In FIG. **10c** the valve member **192** is shown in a position in which the fuel flow passage **193** defines a third flow path connecting the accumulator **140** to the common fuel rail **150**.

The valve member **192** is rotatable by an electric actuator (not shown) in response to a control input from the electronic controller **160** so that the selection of flow path is controlled by the electronic controller **160**.

It will be appreciated that alternative forms of three way diverter valve could be constructed and that the invention is not limited to the rotary diverter valve **190** shown in FIGS. **10a** to **10c**.

Referring back now to FIG. **3**, the common fuel rail **150** is arranged to supply fuel to four fuel injectors I1, I2, I3 and I4, the operation of each of which is controlled by the electronic controller **160**.

Each of the fuel injectors I1, I2, I3 and I4 supply fuel to the engine **10** at the timing and volume required based upon a respective control input received from the electronic controller **160**. Excess fuel from the fuel injectors I1, I2, I3 and I4 is returned to the fuel tank **110** via respective low pressure return lines R1, R2, R3 and R4.

It will be appreciated that the invention is not limited to use with four fuel injectors and that a fuel supply system have less or more fuel injectors could beneficially utilise the invention.

A fuel pressure sensor **170** is arranged to sense the pressure of fuel in the common fuel rail **150** and supply a signal indicative of the sensed pressure to the electronic controller **160**.

The high pressure accumulator **140** can be of any suitable construction. U.S. Pat. No. 7,717,077 discloses a free piston acted on by a spring for use as a fuel accumulator. Such an arrangement would be suitable for use but it is preferred if a sealed bellows type of accumulator such as that shown in FIGS. **11a** and **11b** is used because with such an accumulator no fuel can leak from the accumulator whereas with the free piston accumulator shown in U.S. Pat. No. 7,717,077 there is the potential for fuel to leak past the piston.



7

The accumulator **140** is shown in FIG. **11a** in an empty state and in FIG. **11b** in a full state. The accumulator comprises a body **141** defining a flow passage **142** by which fuel can enter or leave a storage volume **145** defined by a cup shaped piston, a metal bellows **144** and the body **141**. The piston **143** supports the bellows **144** and is slidably supported by the body **141**. A spring **146** biases the piston **143** towards the end of the body **141** at which fuel enters or leaves the storage volume **145** via the flow passage **142**. The bellows **144** is sealed to both the body **141** and the piston **143** and so there is no possibility of leakage of fuel. It will be appreciated that in practice the body **141** will not be a single component but will be constructed to enable assembly of the various components **143**, **144**, **146**.

A fuel pressure sensor **180** is arranged to sense the pressure of fuel in the accumulator **140** and supply a signal indicative of the sensed pressure to the electronic controller **160**.

Operation of the fuel supply system **100** will now be described with reference to FIGS. **7**, **8** and **9**.

FIG. **7** shows a relationship between engine speed and time during an engine shutdown for a prior art engine having a stop-start system and fuel supply system with no fuel accumulator and an engine **10** having a stop-start system **20** and a fuel supply system **100** constructed in accordance with this invention.

Referring firstly to the prior art situation, initially the engine is idling and then at time **T0** the stop-start system initiates an engine shutdown. In the case of the prior art engine the demand level for the high pressure fuel pump is then reduced to the minimum level because fuel is not required in a conventional fuel supply system having no accumulator. The engine begins to slow at time **T0** and will continue to slow, as shown by the line **E2sd**, until the engine finally stops after a period of engine reverse rotation when **T2** seconds have expired from the time **T0**.

Referring now to the situation when a fuel supply system **100** constructed in accordance with this invention is used, initially the engine **10** is, as before, idling and then, as before, at time **T0** the stop-start system **20** initiates an engine shutdown. However, in this case the demand level for the high pressure fuel pump **130** is then increased to or maintained at a high demand level and preferably the maximum possible demand level and fuel is supplied from the high pressure fuel pump **130** to the accumulator **140**. The engine **10** begins to slow at time **T0** and will continue to slow, as shown by the line **E1sd**, until the engine **10** finally stops after a period of engine reverse rotation when **T1** seconds have expired from the time **T0**.

The engine **10** will slow more rapidly in this case because it is required to drive the high pressure fuel pump **130** to charge the accumulator **140**. In addition, because of the braking effect of the high pressure fuel pump **130** on the engine **10**, the magnitude and duration of any reverse engine rotation is reduced.

Therefore the time taken for the engine to stop has been reduced from **T2** seconds, in the case of a prior art engine, to **T1** seconds, in the case of the engine **10** having a fuel supply system according to the invention, by using the high pressure fuel pump **130** to slow the engine **10**.

Operation of the fuel supply system **100** shown in FIG. **3** during the shutdown period is as follows.

Prior to time **T0** the electronic controller **160** controls the fuel injectors **I1**, **I2**, **I3** and **I4** so as to provide fuel at the correct timing and volume to the engine **10**, sets the demand level for the high pressure fuel pump **130** to a level required to satisfy the fuel usage needs of the engine **10** and controls the three way diverter valve **190** so that it adopts the position

8

shown in FIG. **10a** with the valve member **192** in a position in which the fuel flow passage **193** provides a flow path connecting the high pressure fuel pump **130** to the common fuel rail **150**.

While in this operating state the fuel supply system **100** operates as a conventional fuel supply system with fuel being drawn from the fuel tank **110** by the low pressure fuel pump **120**, supplied to the high pressure fuel pump **130** from the low pressure fuel pump **120**, pressurized by the high pressure fuel pump **130** under the control of the electronic controller **160**, supplied to the common fuel rail **150** from the high pressure fuel pump **130** and drawn from the common fuel rail **150** by the fuel injectors **I1**, **I2**, **I3** and **I4** for injection into the engine **10** to meet the current operating demands of the engine **10**.

At time **T0** the electronic controller **160** receives an indication from the stop-start system **20** that the engine **10** is to be stopped. In response to this indication from the stop-start system **20**, the electronic controller **160**, switches off the fuel injectors **I1**, **I2**, **I3**, **I4**, sets the demand level for the high pressure fuel pump **130** to a high level, preferably a maximum demand level, and controls the three way diverter valve **190** so that the valve member **192** adopts the position shown in FIG. **10b** in which the fuel flow passage **193** defines a flow path connecting the high pressure fuel pump **130** to the accumulator **140**. Fuel is then pumped into the accumulator **140** by the high pressure fuel pump **130** until the engine **10** has stopped rotating.

In a case where a signal from the fuel pressure sensor **180** associated with the accumulator **140** indicates that a maximum safe operating pressure for the accumulator **140** has been reached before the engine **10** stops rotating fuel is vented back to the fuel tank **110**. This has the advantage that the high pressure fuel pump **130** is still operating at high demand increasing the deceleration of the engine **10**.

When the time **T1** has elapsed, the engine **10** has stopped rotating and the electronic controller **160** is then preferably operable to control the three way diverter valve **190** so that the valve member **192** adopts the position shown in FIG. **10a** in which the fuel flow passage **193** provides a flow path connecting the high pressure fuel pump **130** to the common fuel rail **150**. The common fuel rail **150** is therefore isolated from the pressurised fuel within the accumulator **140** while the engine **10** is stationary thereby reducing the risk of leakage from the fuel injectors **I1**, **I2**, **I3** and **I4** while the engine **10** is stationary.

FIG. **8** shows a relationship between engine speed and time during an engine start-up for a prior art engine having a stop-start system and fuel supply system with no fuel accumulator and an engine **10** having a stop-start system **20** and a fuel supply system **100** constructed in accordance with this invention.

Referring firstly to the prior art situation, initially the engine is stationary and then at time **T0'** the stop-start system initiates an engine start-up. In the case of the prior art engine the demand level for the high pressure fuel pump is at a high level in order to provide fuel for the engine and the fuel injectors are controlled to supply the required quantity of fuel to the engine. The engine begins to rotate at time **T0'** due to the action of a starter motor and will continue to speed up, as shown by the line **E2su**, and, at time **t2**, the engine has reached a speed **Nt** where it can generate useful power.

Referring now to the situation where a fuel supply system **100** constructed in accordance with this invention is used. As before, initially the engine **10** is stationary and then, as before, at time **T0'** the stop-start system **20** initiates an engine start-up. However, in this case, the demand level for the high pressure fuel pump **130** is set to a low demand level and is

preferably set to a zero demand level. This is made possible because fuel is supplied not by the high pressure fuel pump **130** but from the accumulator **140**. The engine **10** begins to rotate at time  $T_0'$  due to the action of the starter motor **11** and will continue to accelerate, as shown by the line  $E1sd$ , and, at time  $t_1$ , the engine **10** has reached the speed  $N_t$  where it can generate useful power.

The engine **10** will accelerate more rapidly in this case because it is not required to drive the high pressure fuel pump **130** to provide fuel to the engine **10**. In addition, because the fuel is supplied from the accumulator **140**, there is no time delay waiting for the high pressure fuel pump **130** to speed up and generate fuel pressure, the required fuel pressure is immediately available from the accumulator **140** and the first opportunity to inject fuel can be utilised.

Therefore the time taken for the engine to reach the speed  $N_t$  from stationary ( $T_0'$ ) is reduced from  $t_2$  seconds, in the case of a prior art engine, to  $t_1$  seconds, in the case of an engine having a fuel supply system according to the invention.

At some point in time after reaching the engine speed  $N_t$ , fuelling of the engine **10** is switched back to the high pressure fuel pump **130**.

Operation of the fuel supply system **100** shown in FIG. 3 during engine start-up is as follows.

At time  $T_0'$  or at a point in time after the engine **10** has sensed to have stopped but before the time  $T_0'$  the electronic controller **160** is also operable to set the demand level for the high pressure fuel pump **130** to a low level and preferably to the lowest possible level which in some cases is a zero flow demand level.

At time  $T_0'$ , the diverter valve **190** is switched from the position shown in FIG. 10a to the position shown in FIG. 10c to supply fuel from the accumulator **140** to the engine **10**. This switching occurs very rapidly and will have no significant adverse effect on starting of the engine **10** because the time taken to switch the valve **190** is considerably less than the time taken for the first available cylinder of the engine **10** to reach a potential ignition position.

Therefore, at time  $T_0'$  when the stop-start system **20** indicates that the engine **10** is to be started and cranking of the engine commences, the electronic controller **160** can control whichever of the fuel injectors **11**, **12**, **13** and **14** has the first opportunity to inject fuel to the engine **10** to commence injection of fuel into the engine **10** without delay. As fuel is drawn from the common fuel rail **150** by the fuel injectors **11**, **12**, **13** and **14** it is replaced by fuel supplied to the common fuel rail **150** from the accumulator **140** thereby maintaining the fuel pressure in the fuel rail **150** at an appropriate pressure for efficient injection into the engine **10**.

Because the volume of the accumulator **140** is finite, at some point in time after time  $T_0'$  the electronic controller **160** must control the diverter valve **190** to switch the flow path from the accumulator **140** to the high pressure fuel pump **130**. This can occur when the pressure sensor **170** associated with the common fuel rail **150** indicates that the fuel pressure is beginning to drop, when a predefined volume of fuel that is less than the known volume of the accumulator **140** has been injected into the engine or when a power demand on the engine **10** exceeds a predefined level. When this point in time is reached, the electronic controller **160** is operable to control the three way diverter valve **190** so that the valve member **192** moves from the position shown in FIG. 10c to the position shown in FIG. 10a in which the fuel flow passage **193** defines a flow path connecting the high pressure fuel pump **130** to the

common fuel rail **150**. Fuel is then pumped directly into the common fuel rail by the high pressure fuel pump **130** for use by the engine **10**.

With reference to FIG. 9 the combined effect of the improvements in engine shutdown and engine start-up is shown.

The lines  $E2sd$  and  $E2su$  are those representing respectively engine speed during shutdown and start-up for a prior art engine and fuel supply system and the lines  $E1sd$  and  $E1su$  are those representing respectively engine speed during shutdown and start-up for an engine having a fuel supply system constructed in accordance with this invention utilising a control method according to this invention.

The time period "x" is a time delay between the time when the respective engine reaches zero and the time when the subsequent start commences and is identical in both cases.  $T_0$  is the point in time when shutdown of the respective engine commences and the time periods  $T_2$  and  $T_1$  are the periods of time required for the engine to reach zero in the case of a prior art and engine using a fuel supply system and method in accordance with this invention.

In the case of a prior art engine, the time taken from the point in time  $T_0$  when the shutdown commences to the point in time where the engine speed reaches a speed  $N_t$  where useful power can be produced is  $Tt_2$  seconds.

In the case of an engine using a fuel supply system and method in accordance with this invention, the time taken from the point in time  $T_0$  when the shutdown commences to the point in time where the engine speed reaches a speed  $N_t$  where useful power can be produced is  $Tt_1$  seconds.

Therefore a reduction in cycle time of  $T_d$  seconds is produced by using a fuel supply system and method in accordance with this invention.

Referring now to FIGS. 4, 7, 8 and 9 a second embodiment of fuel supply system is shown that is in many respects the same as that previously described and for which the same components have the same reference numerals.

The only significant difference between the second embodiment shown in FIG. 4 and the first embodiment shown in FIG. 3 is that the valve means which is a single three way diverter valve **190** in FIG. 3 is replaced by first and second valves **190A**, **190B** in FIG. 4. The operation of the fuel supply system has the same advantageous effects as previously described and the shutdown and start-up of the engine **10** is as previously described with reference to FIGS. 7, 8 and 9.

Operation of the fuel supply system **100** shown in FIG. 4 during an engine shutdown is as follows.

Prior to time  $T_0$  (FIGS. 7 and 9) the electronic controller **160** controls the fuel injectors **11**, **12**, **13** and **14** so as to provide fuel at the correct timing and volume to the engine **10**, sets the demand level for the high pressure fuel pump **130** to a level required to satisfy the fuel usage needs of the engine **10** and controls the two valves **190A**, **190B** so that fuel flows via first valve **190A** to the common fuel rail **150** but cannot flow to the accumulator **140** via the second valve **190B**.

A flow path is thereby provided connecting the high pressure fuel pump **130** to the common fuel rail **150**.

While in this operating state the fuel supply system **100** operates as a conventional fuel supply system with fuel being drawn from the fuel tank **110** by the low pressure fuel pump **120**, is supplied to the high pressure fuel pump **130** from the low pressure fuel pump **120**, is pressurised by the high pressure fuel pump **130** under the control of the electronic controller **160**, is supplied to the common fuel rail **150** from the high pressure fuel pump **130** and is drawn from the common

## 11

fuel rail 150 by the fuel injectors 11, 12, 13 and 14 for injection into the engine 10 to meet the current operating demands of the engine 10.

At time T0 the electronic controller 160 receives an indication from the stop-start system 20 that the engine 10 is to be stopped. In response to this indication from the stop-start system 20, the electronic controller 160, switches off the fuel injectors 11, 12, 13, 14, sets the demand level for the high pressure fuel pump 130 to a high level, preferably a maximum demand level, and controls the two valves 190A, 190B so that a flow path connecting the high pressure fuel pump 130 to the accumulator 140 is produced. To do this the first valve 190A is closed and the second valve 190B is opened by the electronic controller 160.

Fuel is then pumped into the accumulator 140 by the high pressure fuel pump 130 until the engine 10 has stopped rotating.

As before, in a case where a signal from the fuel pressure sensor 180 associated with the accumulator 140 indicates that a maximum safe operating pressure for the accumulator 140 has been reached before the engine 10 stops rotating, it will be necessary to vent fuel back to the fuel tank 110.

When the time T1 has elapsed, the engine 10 has stopped rotating and the electronic controller 160 is then preferably operable to control the valve 190A so that there is no flow path connecting the accumulator 140 to the common fuel rail 150. The common fuel rail 150 is therefore isolated from the pressurised fuel in the accumulator 140 while the engine 10 is stationary to prevent leakage from the fuel injectors 11, 12, 13 and 14. Preferably, the valve 190B is also closed to prevent leakage back through the high pressure fuel pump 130.

Operation of the fuel supply system 100 shown in FIG. 4 during a subsequent engine start-up is as follows.

At time T0', the two valves 190A, 190B are moved to the positions required to supply fuel from the accumulator 140 to the engine 10. Also, at time T0', when the stop-start system 20 indicates that the engine 10 is to be started and cranking of the engine commences, the electronic controller 160 controls whichever of the fuel injectors 11, 12, 13 and 14 has the first opportunity to inject fuel to the engine 10 to commence injection of fuel into the engine 10 without delay. As fuel is drawn from the common fuel rail 150 by the fuel injectors 11, 12, 13 and 14 it is replaced by fuel supplied to the common fuel rail 150 from the accumulator 140 thereby maintaining the fuel pressure in the fuel rail 150 at an appropriate pressure for efficient injection into the engine 10.

At time T0' (FIG. 8) or preferably at a point in time after the engine 10 has sensed to have stopped but before the time T0', the electronic controller 160 is also operable to set the demand level for the high pressure fuel pump 130 to a low level and preferably to the lowest possible level which in some cases is a zero flow demand level.

Because the volume of the accumulator 140 is finite, at some point in time after time T0', the electronic controller 160 must control the two valves 190A, 190B to switch the flow path from the accumulator 140 to the high pressure fuel pump 130. This switching can occur when the pressure sensor 170 associated with the common fuel rail 150 indicates that the fuel pressure is beginning to drop, when a predefined volume of fuel that is less than the known volume of the accumulator 140 has been injected into the engine or when a power demand on the engine 10 exceeds a predefined level. To switch the flow path, the electronic controller 160 is operable to control the two valves 190A, 190B so that the second valve 190B is closed and the first valve 190A is opened thereby providing a fuel flow path connecting the high pressure fuel pump 130 to the common fuel rail 150. Fuel is then pumped

## 12

once again directly into the common fuel rail 150 by the high pressure fuel pump 130 for use by the engine 10.

Referring now to FIGS. 5, 7, 8 and 9 a third embodiment of fuel supply system is shown that is in some respects the same as that previously described and for which the same components have the same reference numerals.

The third embodiment shown in FIG. 5 differs from the second embodiment shown in FIG. 4 in that the valve means in the form of the first and second valves 190A, 190B are connected to the common fuel rail 150 in a different manner in FIG. 5.

In FIG. 4 the two valves 190A, 190B are both connected to the common fuel rail 150 by a common supply line whereas in FIG. 5 separate supply lines are used. The flow of fuel does not therefore have to pass from the accumulator 140 through the first valve 190A to reach the common fuel rail 150 in the case of the third embodiment shown in FIG. 5 but does have to in the second embodiment shown in FIG. 4. That is to say, the high pressure fuel pump 130 and the accumulator 140 are independently connectable to the common fuel rail 150 in the case of the third embodiment shown in FIG. 5. In the third embodiment the fuel from the high pressure fuel pump 130 to the accumulator 140 is controlled by the first valve 190A.

Therefore in both embodiments the first valve 190A provides two flow paths whereas the second valve 190B provides only one flow path. The first valve 190A is therefore a two way diverter valve whereas the second valve 190B is a simple flow control valve having at least open and closed positions.

The operation of the fuel supply system shown in FIG. 5 has the same advantageous effects as previously described and the shutdown and start-up of the engine 10 is as previously described with reference to FIGS. 7, 8 and 9.

Operation of the fuel supply system 100 shown in FIG. 5 during an engine shutdown is as follows.

Prior to time T0 (FIGS. 7 and 9) the electronic controller 160 controls the fuel injectors 11, 12, 13 and 14 so as to provide fuel at the correct timing and volume to the engine 10, sets the demand level for the high pressure fuel pump 130 to a level required to satisfy the fuel usage needs of the engine 10 and controls the two valves 190A, 190B so that fuel flows via first valve 190A to the common fuel rail 150 but cannot flow from the accumulator 140 to the common fuel rail 150 via the second valve 190B. To do this the second valve 190B is closed and the first valve 190A is placed in a position in which a flow path between the high pressure fuel pump 130 and the common fuel rail 150 is provided but no flow path is provided between the high pressure fuel pump 130 and the accumulator 140.

While in this operating state the fuel supply system 100 operates as a conventional fuel supply system as previously described with reference to FIGS. 3 and 4.

At time T0 the electronic controller 160 receives an indication from the stop-start system 20 that the engine 10 is to be stopped. In response to this indication from the stop-start system 20, the electronic controller 160, switches off the fuel injectors 11, 12, 13, 14, sets the demand level for the high pressure fuel pump 130 to a high level, preferably a maximum demand level, and controls the two valves 190A, 190B so that a flow path connecting the high pressure fuel pump 130 to the accumulator 140 is produced. To do this, the first valve 190A is moved to a position connecting the high pressure fuel pump 130 to the accumulator 140 and the second valve 190B is kept closed by the electronic controller 160.

Fuel is then pumped into the accumulator 140 by the high pressure fuel pump 130 until the engine 10 has stopped rotating.

## 13

As before, in a case where a signal from the fuel pressure sensor **180** associated with the accumulator **140** indicates that a maximum safe operating pressure for the accumulator **140** has been reached before the engine **10** stops rotating, it will be necessary to vent fuel back to the fuel tank **110**.

When the time **T1** has elapsed, the engine **10** has stopped rotating and the electronic controller **160** is then preferably operable to control the two valves **190A**, **190B** so that the two valves **190A** and **190B** provide no flow path connecting the accumulator **140** to the common fuel rail **150**. To do this the second valve **190B** is closed and the first control valve **190A** is preferably left in the current closed position or be repositioned so as to connect the common fuel rail **150** to the high pressure fuel pump **130**.

It will be appreciated that if the first valve **190A** is not in a flow blocking position then the high pressure fuel pump **130** must either be of a construction where back flow from the high pressure fuel pump **130** to the low pressure fuel pump **120** or fuel tank is not possible or must include a non-return valve to prevent such flow. Such a fuel pump will be referred to hereinafter as being a 'non-return flow' high pressure fuel pump. A non-return fuel pump could be used in other embodiments of fuel supply system shown and described herein.

Operation of the fuel supply system **100** shown in FIG. **5** during a subsequent engine start-up is as follows.

At time **T0'** (FIG. **8**) or at a point in time after the engine **10** has sensed to have stopped but before the time **T0'** the electronic controller **160** is operable to set the demand level for the high pressure fuel pump **130** to a low level and preferably to the lowest possible level which in some cases is a zero flow demand level.

At time **T0'**, the second valve **190B** is opened to a position required to supply fuel from the accumulator **140** to the engine **10** and the common fuel rail **150** is pressurised with fuel. Therefore, at time **T0'** when the stop-start system **20** indicates that the engine **10** is to be started and cranking of the engine commences, the electronic controller **160** can control whichever of the fuel injectors **I1**, **I2**, **I3** and **I4** has the first opportunity to inject fuel to the engine **10** to commence injection of fuel into the engine **10** without delay. As fuel is drawn from the common fuel rail **150** by the fuel injectors **I1**, **I2**, **I3** and **I4** it is replaced by fuel supplied to the common fuel rail **150** from the accumulator **140** thereby maintaining the fuel pressure in the fuel rail **150** at an appropriate pressure for efficient injection into the engine **10**.

As before, because the volume of the accumulator **140** is finite, at some point in time after time **T0'**, the electronic controller **160** must control the two valves **190A**, **190B** to switch the flow path to the engine **10** from the accumulator **140** to the high pressure fuel pump **130**. As previously discussed, this can occur when the pressure sensor **170** associated with the common fuel rail **150** indicates that the fuel pressure is beginning to drop, when a predefined volume of fuel that is less than the known volume of the accumulator **140** has been injected into the engine or when a power demand on the engine **10** exceeds a predefined level.

To achieve this flow switching, the electronic controller **160** is operable to control the two valves **190A**, **190B** so that the second valve **190B** is closed and the first valve **190A** is either repositioned or maintained in the position required to provide a fuel flow path connecting the high pressure fuel pump **130** to the common fuel rail **150**. Fuel is then pumped once again directly into the common fuel rail **150** by the high pressure fuel pump **130** for use by the engine **10**.

Referring now to FIGS. **6**, **7**, **8** and **9**, a preferred or fourth embodiment of fuel supply system is shown that is in some

## 14

respects the same as that previously described and for which the same components have the same reference numerals.

The fourth embodiment shown in FIG. **6** differs from the third embodiment shown in FIG. **5** in that the valve means in the form of the first and second valves **190A**, **190B** used in the third embodiment are replaced by a single valve **290** located in the same position as the second valve **190B** and being of the same construction as the simple control valve **190B** in that it has at least open and closed positions.

In the fourth embodiment shown in FIG. **6** there is no valve controlling the flow of fuel from the high pressure fuel pump **130** to the common fuel rail **150** and so the high pressure fuel pump **130** is permanently connected to the common fuel rail **150**.

The flow of fuel from the accumulator **140** to the common fuel rail **150** is controlled by the electronically controlled valve **290**. However, in this case, the flow of fuel can be in either direction through the valve **290** because not only is fuel supplied to the common fuel rail **150** from the accumulator **140** through the valve **290** it is received by the accumulator **140** from the high pressure fuel pump **130** via the common fuel rail **150** and valve **290**. Such an arrangement requires the use of a 'non-return' high pressure fuel pump **130** previously referred to with respect to FIG. **5**.

The operation of the fuel supply system shown in FIG. **6** has the same advantageous effects as previously described and the shutdown and start-up of the engine **10** is as previously described with reference to FIGS. **7**, **8** and **9**.

Operation of the fuel supply system **100** shown in FIG. **6** during an engine shutdown is as follows.

Prior to time **T0** (FIGS. **7** and **9**) the electronic controller **160** controls the fuel injectors **I1**, **I2**, **I3** and **I4** so as to provide fuel at the correct timing and volume to the engine **10**, sets the demand level for the high pressure fuel pump **130** to a level required to satisfy the fuel usage needs of the engine **10** and controls the valve **290** so that fuel cannot flow from the common fuel rail **150** to the accumulator **140**. To do this the valve **290** is closed.

While in this operating state the fuel supply system **100** operates as a conventional fuel supply system as previously described with reference to FIGS. **3** and **4**.

At time **T0** the electronic controller **160** receives an indication from the stop-start system **20** that the engine **10** is to be stopped. In response to this indication from the stop-start system **20**, the electronic controller **160**, switches off the fuel injectors **I1**, **I2**, **I3**, **I4**, sets the demand level for the high pressure fuel pump **130** to a high level, preferably a maximum demand level, and controls the valve **290** so that a flow path connecting the high pressure fuel pump **130** to the accumulator **140** via the common fuel rail **150** is produced. To do this the valve **290** is moved to an open position.

Fuel is then pumped into the accumulator **140** by the high pressure fuel pump **130** until the engine **10** has stopped rotating.

As before, in a case where a signal from the fuel pressure sensor **180** associated with the accumulator **140** indicates that a maximum safe operating pressure for the accumulator **140** has been reached before the engine **10** stops rotating, it will be necessary to either reduce the demand level to the high pressure fuel pump **130** to a minimum level and/or vent fuel back to the fuel tank **110**.

When the time **T1** (FIG. **7**) has elapsed, the engine **10** has stopped rotating and the electronic controller **160** is then operable to control the valve **290** so as to provide no flow path connecting the accumulator **140** to the common fuel rail **150** to prevent fuel leakage as previously referred to.

15

It will be appreciated that with such an arrangement the high pressure fuel pump **130** should be of a 'non-return flow' high pressure fuel pump or fuel could leak back to the fuel tank **110** when the accumulator **140** is connected to the common fuel rail **150** and the high pressure fuel pump **130** is operating a low demand.

Operation of the fuel supply system **100** shown in FIG. **6** during a subsequent engine start-up is as follows.

At time **T0'** (FIG. **8**) or at a point in time after the engine **10** has sensed to have stopped but before the time **T0'** the electronic controller **160** is operable to set the demand level for the high pressure fuel pump **130** to a low level and preferably to the lowest possible level which in some cases is a zero flow demand level.

At time **T0'**, the valve **290** is opened to a position required to supply fuel from the accumulator **140** to the engine **10** and the common fuel rail **150** is pressurised with fuel. Therefore, at time **T0'** when the stop-start system **20** indicates that the engine **10** is to be started and cranking of the engine commences, the electronic controller **160** can control whichever of the fuel injectors **11**, **12**, **13** and **14** has the first opportunity to inject fuel to the engine **10** to commence injection of fuel into the engine **10** without delay. As fuel is drawn from the common fuel rail **150** by the fuel injectors **11**, **12**, **13** and **14** it is replaced by fuel supplied to the common fuel rail **150** from the accumulator **140** thereby maintaining the fuel pressure in the fuel rail **150** at an appropriate pressure for efficient injection into the engine **10**.

Because the volume of the accumulator **140** is finite, at some point in time after time **T0'**, the electronic controller **160** is operable to close the valve **290** after which time the flow path to the engine **10** is solely from the high pressure fuel pump **130** and the demand for the high pressure fuel pump **130** is increased to the level required to supply fuel to the engine **10**.

Because the high pressure fuel pump **130** is permanently connected to the common fuel rail **150**, the supply of fuel is continuous and there is no actual flow switchover required. As the high pressure fuel pump **130** accelerates with the engine **10** it will reach a speed where it will be able to provide the required fuel pressure and this will normally occur before the valve **290** is closed.

One of the advantages of the third and fourth embodiments shown in FIGS. **5** and **6** respectively is that, if required, the accumulator **140** could be topped up with fuel by the high pressure fuel pump **130** at the same time fuel is being supplied to the common fuel rail **150** by the high pressure fuel pump **130**.

It will be appreciated by those skilled in the art that although the invention has been described by way of example with reference to one or more embodiments it is not limited to the disclosed embodiments and that alternative embodiments could be constructed without departing from the scope of the invention as defined by the appended claims.

In this way, a method of controlling a fuel supply system of an engine of a motor vehicle wherein the method comprises, during a shutdown of the engine, operating an engine driven variable output high pressure fuel pump at a high demand level and storing fuel from the high pressure fuel pump in a fuel accumulator and, during a subsequent engine start-up, operating the high pressure fuel pump at a low demand level and supplying fuel from the accumulator to the engine. The high demand level may be the maximum demand level of the high pressure fuel pump.

The low demand level may be the minimum demand level of the high pressure fuel pump. The motor vehicle may be a stop-start enabled motor vehicle having a stop-start controller

16

to control stopping and starting of the engine and the shutdown and subsequent start-up of the engine are initiated by the stop-start controller.

As such, a fuel supply system of an engine of a motor vehicle comprising an engine driven variable output high pressure fuel pump, a fuel accumulator to store fuel at high pressure, a valve means to control the flow of high pressure fuel within the system and an electronic controller to control the operation of the high pressure fuel pump and the valve means, wherein the controller is operable during a shutdown of the engine, to operate the high pressure fuel pump at a high demand level and control the valve means to store fuel from the high pressure fuel pump in the fuel accumulator and is operable, during a subsequent engine start-up, to operate the high pressure fuel pump at a low demand level and operate the valve means so that fuel from the fuel accumulator is supplied to the engine. The valve means may include at least one valve to selectively isolate the accumulator from the engine and the high pressure fuel pump. This has the advantage that fuel can be supplied to the accumulator only when the high pressure pump can recover energy from the engine thereby reducing the fuel consumption of the engine.

The system may further comprise a fuel reservoir, a low pressure fuel pump to supply fuel from the reservoir to the high pressure fuel pump and at least one fuel injector to supply fuel at high pressure to the engine wherein the controller is operable during a shutdown of the engine, to operate the high pressure fuel pump at a high demand level and to control the valve means to store fuel from the high pressure fuel pump in the fuel accumulator and, during a subsequent engine start-up, is operable to operate the high pressure fuel pump at a low demand level, to operate the valve means so that fuel from the fuel accumulator is supplied to the at least one fuel injector and to control the at least one fuel injector to supply fuel to the engine. There may be at least two fuel injectors, fuel may be supplied to the fuel injectors via a common fuel rail and the valve means may include at least one valve controlled by the electronic controller to control the flow of fuel between the accumulator and the common fuel rail.

This has the advantage that, if the engine is stationary for a long period of time the fuel remains stored in the accumulator with reduced risk of leakage via the at least two fuel injectors. The valve means may comprise a single diverter valve interposed between the high pressure fuel pump and the common fuel rail, between the high pressure fuel pump and the accumulator and between the accumulator and the common fuel rail. The diverter valve may have three selectable fuel flow paths, a first flow path connecting, when selected, the high pressure fuel pump to the common fuel rail, a second flow path connecting, when selected, the high pressure fuel pump to the accumulator and a third flow path connecting, when selected, the accumulator to the common fuel rail and the selection of each respective flow path is controlled by the electronic controller.

Alternatively, the valve means may comprise a first electronically controlled valve to control the flow of fuel from the high pressure fuel pump to the common fuel rail and a second electronically controlled valve to control the flow of fuel from the high pressure fuel pump to the accumulator wherein a flow path from the accumulator to the common fuel rail passes through both the first and the second electronically controlled valves.

As yet a further alternative, the valve means may comprise a first electronically controlled valve to control the flow of fuel from the high pressure fuel pump to the common fuel rail, a second electronically controlled valve to control the flow of

17

fuel between the accumulator and the common fuel rail wherein a flow path from the high pressure fuel pump to the accumulator is also controlled by the first electronically controlled valve.

During shutdown of the engine, the first electronically controlled valve may be controlled by the electronic controller to permit fuel to flow from the high pressure fuel pump to the accumulator and the second electronically controlled valve is closed so as to prevent the flow of fuel from the accumulator to the common fuel rail. During start-up of the engine, the fuel injectors may be controlled by the electronic controller to supply fuel to the engine and the second electronically controlled valve may be controlled by the electronic controller to permit fuel to flow from the accumulator to the common fuel rail.

As yet a further alternative there may be no control valve between the high pressure fuel pump and the common fuel rail, the valve means may comprise an electronically controlled valve to control the flow of fuel between the accumulator and the common fuel rail and a flow path from the high pressure fuel pump to the accumulator may pass through the common fuel rail and the electronically controlled valve. During shutdown of the engine, all fuel injectors may be switched off by the electronic controller and the electronically controlled valve may be controlled by the electronic controller to permit fuel to flow from the high pressure fuel pump via the common fuel rail to the accumulator. During start-up of the engine, the fuel injectors may be controlled by the electronic controller to supply fuel to the engine and the electronically controlled valve may be controlled by the electronic controller to permit fuel to flow from the accumulator to the common fuel rail. The high pressure fuel pump may be a non-return high pressure fuel pump. The high demand level may be the maximum demand level of the high pressure fuel pump.

The low demand level may be the minimum demand level of the high pressure fuel pump. The motor vehicle may be a stop-start enabled motor vehicle having a stop-start controller to control stopping and starting of the engine and the shutdown and subsequent start-up of the engine may be initiated by the stop-start controller.

According to a third aspect of the invention there is provided a motor vehicle having a fuel supply system constructed in accordance with said second aspect of the invention.

Note that the example control and estimation routines included herein can be used with various engine and/or vehicle system configurations. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the engine control system.

It will be appreciated that the configurations and routines disclosed herein are exemplary in nature, and that these spe-

18

cific embodiments are not to be considered in a limiting sense, because numerous variations are possible. For example, the above technology can be applied to V-6, I-4, I-6, V-12, opposed 4, and other engine types. The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various systems and configurations, and other features, functions, and/or properties disclosed herein.

The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to “an” element or “a first” element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

The invention claimed is:

1. A method of controlling an engine fuel supply system, comprising:

25 during a shutdown of the engine, operating an engine driven variable output high pressure fuel pump at a high demand level and storing fuel from the high pressure fuel pump in a fuel accumulator and, during a subsequent engine start-up, operating the high pressure fuel pump at a low demand level and supplying fuel from the accumulator to the engine.

2. The method of claim 1 wherein the high demand level is a maximum demand level of the high pressure fuel pump.

3. The method of claim 1 wherein the low demand level is a minimum demand level of the high pressure fuel pump.

4. The method of claim 3 wherein the motor vehicle is a stop-start enabled motor vehicle having a stop-start controller to control stopping and starting of the engine and the shutdown and subsequent start-up of the engine are initiated by the stop-start controller.

5. A fuel supply system of an engine of a motor vehicle comprising:

an engine driven variable output high pressure fuel pump, a fuel accumulator to store fuel at high pressure, a valve means to control a flow of high pressure fuel within the system and an electronic controller to control operation of the high pressure fuel pump and the valve means, wherein the controller is operable during a shutdown of the engine, to operate the high pressure fuel pump at a high demand level and control the valve means to store fuel from the high pressure fuel pump in the fuel accumulator, and is operable, during a subsequent engine start-up, to operate the high pressure fuel pump at a low demand level and operate the valve means so that fuel from the fuel accumulator is supplied to the engine.

6. The fuel supply system of claim 5, wherein the valve means includes at least one valve to selectively isolate the accumulator from the engine and the high pressure fuel pump.

7. The fuel supply system of claim 5 in which the system further comprises, a fuel reservoir, a low pressure fuel pump to supply fuel from the reservoir to the high pressure fuel pump and at least one fuel injector to supply fuel at high pressure to the engine wherein the controller is operable during a shutdown of the engine, to operate the high pressure fuel pump at a high demand level and to control the valve means to store fuel from the high pressure fuel pump in the fuel accumulator and, during a subsequent engine start-up, is

19

operable to operate the high pressure fuel pump at a low demand level, to operate the valve means so that fuel from the fuel accumulator is supplied to the at least one fuel injector and to control the at least one fuel injector to supply fuel to the engine.

8. The fuel supply system of claim 7, wherein there are at least two fuel injectors, fuel is supplied to the fuel injectors via a common fuel rail and the valve means includes at least one valve controlled by the electronic controller to control a flow of fuel between the accumulator and the common fuel rail.

9. The fuel supply system of claim 8, in which the valve means comprises a single diverter valve interposed between the high pressure fuel pump and the common fuel rail, between the high pressure fuel pump and the accumulator, and between the accumulator and the common fuel rail.

10. The fuel supply system of claim 9, wherein the diverter valve has three selectable fuel flow paths, a first flow path connecting, when selected, the high pressure fuel pump to the common fuel rail, a second flow path connecting, when selected, the high pressure fuel pump to the accumulator, and a third flow path connecting, when selected, the accumulator to the common fuel rail, wherein the selection of each respective flow path is controlled by the electronic controller.

11. The fuel supply system of claim 8, in which the valve means comprises a first electronically controlled valve to control a flow of fuel from the high pressure fuel pump to the common fuel rail and a second electronically controlled valve to control a flow of fuel from the high pressure fuel pump to the accumulator, wherein a flow path from the accumulator to the common fuel rail passes through both the first and the second electronically controlled valves.

12. The fuel supply system of claim 8 in which the valve means comprises a first electronically controlled valve to control a flow of fuel from the high pressure fuel pump to the common fuel rail, and a second electronically controlled valve to control a flow of fuel between the accumulator and the common fuel rail, wherein a flow path from the high pressure fuel pump to the accumulator is also controlled by the first electronically controlled valve.

13. The fuel supply system of claim 12, wherein, during shutdown of the engine, the first electronically controlled

20

valve is controlled by the electronic controller to permit fuel to flow from the high pressure fuel pump to the accumulator and the second electronically controlled valve is closed so as to prevent the flow of fuel from the accumulator to the common fuel rail.

14. The fuel supply system of claim 12 wherein, during start-up of the engine, the fuel injectors are controlled by the electronic controller to supply fuel to the engine and the second electronically controlled valve is controlled by the electronic controller to permit fuel to flow from the accumulator to the common fuel rail.

15. The fuel supply system of claim 8, wherein there is no control valve between the high pressure fuel pump and the common fuel rail, the valve means comprises an electronically controlled valve to control a flow of fuel between the accumulator and the common fuel rail and a flow path from the high pressure fuel pump to the accumulator passes through the common fuel rail and the electronically controlled valve.

16. The fuel supply system of claim 15 wherein, during shutdown of the engine, all fuel injectors are switched off by the electronic controller and the electronically controlled valve is controlled by the electronic controller to permit fuel to flow from the high pressure fuel pump via the common fuel rail to the accumulator.

17. The fuel supply system of claim 15 wherein, during start-up of the engine, the fuel injectors are controlled by the electronic controller to supply fuel to the engine and the electronically controlled valve is controlled by the electronic controller to permit fuel to flow from the accumulator to the common fuel rail.

18. The fuel supply system of claim 5, wherein the high pressure fuel pump is a non-return high pressure fuel pump.

19. The fuel supply system of claim 5, wherein the high demand level is a maximum demand level of the high pressure fuel pump.

20. The fuel supply system of claim 5, wherein the low demand level is a minimum demand level of the high pressure fuel pump.

\* \* \* \* \*